BB

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 September 2001 (27.09.2001)

PCT

(10) International Publication Number
WO 01/72099 A2

(51) International Patent Classification[7]: H05K 7/20

(21) International Application Number: PCT/US01/08871

(22) International Filing Date: 20 March 2001 (20.03.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/190,881 21 March 2000 (21.03.2000) US

(71) Applicant: **LIEBERT CORPORATION** [US/US]; 1050 Dearborn Drive, Columbus, OH 43085 (US).

(72) Inventor: **BAER, Daniel, B.**; 5250 Olentangy River Road, Delaware, OH 43015 (US).

(74) Agent: **ALLEN, Billy, C., III**; Howrey Simon Arnold & White, LLP, 750 Bering Drive, Houston, TX 77057-2198 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published:**
— *without international search report and to be republished upon receipt of that report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

WO 01/72099 A2

(54) Title: METHOD AND APPARATUS FOR COOLING ELECTRONIC ENCLOSURES

(57) **Abstract:** The present invention is directed to a cooling apparatus and method, and more particularly, an apparatus and method for cooling the air exiting the enclosure causes the enclosure to present a neutral heat load to a room containing such enclosure. Cooling the exiting an electronics enclosure. Cooling the air exiting air obviates the necessity of increasing the room air conditioning capacity to account for the heat added to the room by the electronics within the enclosure. Further, the invention decreases the possibility of moisture condensation within the enclosure and also provides a more efficient cooling system than is available from prior art devices and techniques.

# METHOD AND APPARATUS FOR COOLING ELECTRONIC ENCLOSURES

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/190,881, filed March 21, 2000.

## BACKGROUND OF THE INVENTION

With the expansion of telecommunication and computer technology, increasing amounts of electronic equipment are required at various commercial and business facilities. To facilitate interconnection and access to such equipment, it is typically installed in a common room. Further, technological advancements are permitting more and more electronic equipment to be fit into increasingly smaller spaces. These forces are combining to produce relatively dense electronic installations that generate increasing amounts of heat. For such equipment to operate properly, and to maintain comfort for persons operating and working on such equipment, it is necessary to provide a relatively stable and comfortable temperature and humidity. This has typically been accomplished through the use of air conditioning.

As the density of electronic equipment has increased, it has become increasingly difficult to remove the heat introduced by the electronics from the rooms where such equipment is operated using the conventional room air conditioning alone. It has therefore become necessary to install additional localized cooling for enclosures containing electronic equipment that will remove the heat generated by the electronic equipment from the room, thereby minimizing or eliminating the heat load on the air conditioning equipment.

## SUMMARY OF THE INVENTION

The present invention is an apparatus and method for removing heat generated by the electronics within an enclosure from the room containing such enclosure, thereby reducing or eliminating the heat load from the conventional room air conditioning system. In fact, using the present invention it is possible to supplement the cooling capacity of the room air conditioning system to promote efficient operation.

The principle of operation of the present system is as follows: Air from the computer room at the ambient temperature and humidity is taken into the enclosure and

heated by the electronic equipment. The air is then expelled through a heat exchanger. which cools the air back to the ambient temperature. The exiting air is cooled using an external source of chilled water, glycol or a suitable dielectric fluid. which is typically readily available in commercial installations. By returning the air exiting the enclosure to the ambient temperature in the room. the load on the room air conditioning is reduced or eliminated. Furthermore, the cooling fluid provides a more efficient heat transfer medium for removing heat from the room than the room air. as would be the case with a conventional prior art cooling system.

In accordance with one aspect of the present invention. there is provided a cooling system for an enclosure. The enclosure contains equipment that produces heat and is disposed in a room having ambient air. The cooling system includes a heat exchanger attached to the enclosure. The room air enters the enclosure and absorbs heat from the equipment in the enclosure. The heat exchanger absorbs heat from the air and returns the air to the room at substantially the same ambient conditions of the ambient air in the room.

In accordance with another aspect of the present invention. there is provided a mechanism for moving air from the enclosure. through the heat exchanger. and back into the room.

In accordance with one aspect of the present invention. there is provided an enclosure in a computer room. The enclosure contains electronic equipment that produces a heat load. The enclosure includes an inlet for the ambient air from the computer room and an outlet for the heated air in the enclosure. The air absorbs the heat load from the electronic equipment. A heat exchanger adjacent to the outlet of the enclosure absorbs the heat load from the air in the enclosure. The air returns to the computer room at substantially the same ambient conditions as the ambient air in the computer room.

In accordance with one aspect of the present invention. there is provided a method for cooling an enclosure in a computer room. The enclosure contains electronics that produce a heat load. The method includes absorbing the heat load of the electronics by passing the air from the computer room over the electronics in the enclosure. The method further includes absorbing the heat from the heated air by passing the heated air through a heat exchanger. The heat exchanger expels the absorbed heat outside the computer room, while returning the cooled air to the computer room.

In accordance with one aspect of the present invention, there is provided a cooling apparatus for an enclosure disposed in a computer room. The enclosure contains equipment producing heat. The cooling system includes a rack mount in the enclosure. An airflow mechanism is installed in the enclosure, which draws air through the enclosure where the air absorbs heat from the equipment. A heat exchanger installs in the rack mount. The heat exchanger is in fluid association with an external cooling source outside the computer room. The heat exchanger absorbs heat from the air passing through the heat exchanger. The enclosure, therefore, presents a small to non-existent heat load to the computer room in which it is disposed.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing, the preferred embodiment, and other aspects of the present invention will be best understood with reference to the detailed description of specific embodiments of the invention, which follows, when read in conjunction with the accompanying drawings, in which:

Figure 1 shows a side view of an electronic equipment enclosure and cooling system in accordance with the present invention.

Figure 2 shows the rear view of the electronics enclosure, which presents a face-on view of the cooling system of the present invention.

Figure 3 shows an enlarged side view of a cooling system in accordance with the present invention.

Figure 4 illustrates a bottom view of the heat exchanger piping used in the present invention.

Figure 5 shows a top view of the heat exchanger piping used in the present invention.

Figure 6A-6B illustrate embodiments of the present invention, including an airflow inducing mechanism.

Figure 7 illustrates an embodiment of a modulating valve and piping arrangement according to the present invention.

Figure 8 illustrates another embodiment of the present invention.

While the present invention is susceptible to various modifications and alternative forms, specific embodiments are shown by way of example in the drawings and are described in detail herein. However, it should be understood that the invention is

not limited to the particular forms disclosed. Rather. the invention includes all modifications, equivalents and alternatives within the scope of the appended claims.

## DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

An apparatus in accordance with the present invention is illustrated in Fig. 1. Electronic equipment. such as computer or telecommunication devices. is housed in a rack enclosure. Rack enclosure contains a plurality of equipment mounting racks. Mounting racks hold various computer and electronic equipment. Cooling fans integral to the computer equipment draw air from the room. through the front of enclosure. The air passes over the electronic equipment mounted in racks and absorbs the heat generated by the electronics. The air flows out the back of enclosure and back into the computer room.

Because the air used to cool the electronic equipment is returned to the room. the room air conditioning equipment must have adequate capacity to absorb the heat rejected to the room air by the computer equipment. The power dissipation of a typical rack system in use today is approximately 8 kW. However. with the trend of increasingly smaller and faster computer and electronic devices. it is anticipated that a typical rack system will dissipate 15 kW of heat within the next few years. Given the number of such rack systems installed in computer rooms, it is becoming increasingly difficult to cool the room air sufficiently to absorb the heat produced by the electronic equipment.

It is therefore preferable to have a means of cooling that does not reject heat into the computer room. such as the present invention. Turning again to Fig. 1. heat exchanger is mounted on the rear of rack enclosure. As discussed above. air is drawn from the room through the front of rack enclosure. The air passes over the electronic equipment mounted in racks and through heat exchanger. Heat exchanger absorbs the heat added to the air by the electronic equipment, thereby eliminating the additional heat load to the room air conditioning system. The air then returns to the computer room.

In a typical embodiment of the present invention. the ambient air in the computer room would be at a temperature of 75 degrees Fahrenheit. The rack mounted electronic equipment would add heat to this air raising its temperature to a typical value of 95 degrees Fahrenheit. To present a neutral heat load to the computer room air conditioning system, the heat exchanger must absorb all of the heat added to the air. thereby reducing its temperature to the 75 degrees ambient temperature of the computer

room. This heat is then rejected into a source of chilled water, glycol, dielectric fluid or other fluid, which is typically available in buildings where such equipment is housed.

It may be desirable to isolate the cooling fluid used in the cooling device of the present invention from the cooling fluid provided by the external source. For example, the building housing the rack cooler may use chilled water as a cooling fluid. It may then be desirable to use a different cooling fluid with different dielectric properties, within the present invention. The use of a fluid having different dielectric properties will prevent catastrophic damage to the electronic equipment in case of a leak. Furthermore, the amount of isolated cooling fluid required for the rack cooler is limited, meaning less fluid would escape if a leak were to occur.

Isolating the cooling fluid used in the present invention from the cooling fluid of the source may be readily accomplished using a fluid to fluid heat exchanger, as is known in the art. The fluid to fluid heat exchanger may use pumps, valves, sensors and controller to ensure the temperature exchange between the cooling fluid of the source and the cooling fluid in the rack cooler. Additionally, by isolating the cooling fluid used in the present invention, the pressure of the isolated cooling fluid may be controlled. The pressure of the isolated cooling fluid may be made equal to atmospheric pressure minus the head pressure of the cooling fluid. If a leak were to occur in the present invention, air would enter through the leak, and the isolated cooling fluid would be prevented from escaping.

The construction of heat exchanger is illustrated in Fig. 2. Heat exchanger is mounted on the back of enclosure. The heat exchanger is made up of a number of cooling tubes that pass through cooling fins. Chilled water, glycol, dielectric fluid or another cooling fluid from source enters the heat exchanger through modulating valve. Modulating valve is operated by a temperature controller to ensure that the air exiting the heat exchanger is at the same temperature as the room temperature of the computer room in which the equipment is housed. Temperature controller may have a temperature sensor on the back of heat exchanger to measure the temperature of the air leaving the heat exchanger. The chilled cooling fluid then passes into inlet header.

From inlet header, the chilled cooling fluid passes upward through cooling tubes, which are in thermal contact with fins. Air that has been heated by the electronic equipment is flowing through the heat exchanger in a direction parallel to the plane of the fins and perpendicular to the cooling tubes. The fluid passing through tubes absorbs

heat from the air. The cooling fluid then reaches top header at the top of the heat exchanger and returns downward through another set of cooling tubes. The fluid absorbs additional heat from the airflow across the electronic components and reaches the outlet header located at the bottom of heat exchanger. The cooling fluid. now heated is returned through fluid return. The cooling fluid flows to an external cooling source that rejects the heat absorbed by the fluid outside the computer room. The external cooling source may be a chiller or a second heat exchanger. The chilled fluid is then returned to the inlet, operating the cycle continuously.

A preferred embodiment of the cooling system of the present invention includes vent located at the top header of heat exchanger. This vent provides a mechanism whereby the air present in the cooling tubes may be expelled from the system when the heat exchanger is charged with cooling fluid. The preferred embodiment also includes drain, located at either the inlet header or outlet header at the bottom of heat exchanger. This drain provides means whereby the cooling fluid may be drained from the heat exchanger tubes as required for maintenance purposes.

Fig. 3. in conjunction with Fig. 4 and Fig. 5. illustrates the flow of cooling fluid through the apparatus of the present invention. Turning to Fig. 4, a bottom view of the heat exchanger is shown. The cooling fluid enters the heat exchanger from cooling fluid source. The flow of cooling fluid is modulated by valve to regulate the amount of cooling fluid passing through the exchanger. which in turn controls the amount of heat absorbed and the temperature of the exiting air. The cooling fluid then enters inlet header and passes upward through cooling tubes.

Turning now to Fig. 3, a side view of the heat exchanger is shown. The fluid passes upward through cooling tubes, which are in thermal contact with cooling fins. Airflow through the apparatus is in a direction from left to right in the plane of the page. The cooling fluid then reaches top header, which is more clearly illustrated by Fig. 5. In the top header of Fig. 5, the fluid comes up through cooling tubes and flows around to pass downward through cooling tubes. Fluid flow is in a counter clockwise direction through top header. although the header could be constructed in various fashions. Furthermore, the device could be constructed without the top header, with the connection between the upward cooling tubes and the corresponding downward cooling tubes being made by a series of hairpin bends. Returning to Fig. 3, the cooling fluid passes downward through cooling tubes and returns to outlet header, which is more clearly

illustrated in Fig. 4. As can be seen, the cooling fluid passes through outlet header to cooling fluid return piping.

In addition to providing a cooling means for electronic equipment that is heat neutral to the room air conditioning, the present invention has an additional advantage in that it prevents condensation on or near the electronic equipment. Prior art cooling systems for electronic enclosures cooled the air entering the enclosure, which then passed over the electronic equipment and was heated back to the room air temperature by the electronics.

It is well known to those skilled in the art that the amount of water that the air can hold decreases significantly with a decrease in temperature. For example, a typical computer room installation would have an ambient condition of 75 degrees Fahrenheit and a relative humidity of 50 percent. Using standard psychometric calculations, it can be shown that this corresponds to an absolute humidity of approximately 0.009 pounds of water per pound of air. Cooling this air to a temperature of 55 degrees Fahrenheit increases the relative humidity to 100 percent, meaning condensation is imminent. This condensation will take place inside the computer rack enclosure, which poses significant risk to the electronic equipment. Furthermore, if the enclosure is opened, the influx of warm, relatively moist air will virtually guarantee condensation on the electronic equipment.

Conversely, using the present invention, the ambient air enters the enclosure at a typical temperature of 75 degrees Fahrenheit and a typical relative humidity of 50 percent. The air is heated by the electronic components to a typical temperature of 95 degrees Fahrenheit. This decreases the relative humidity of the air to approximately 26 percent. When the heat is removed by the heat exchanger, the relative humidity again increases to a typical value of 50 percent. Because the air is always contains a relatively low amount of water as compared to saturation, the possibility of condensation is virtually non-existent.

The cooling technique of the present invention has the added advantage of allowing the use of a relatively warmer cooling fluid. To efficiently transfer heat from the heated air to the cooling fluid, it is typically necessary to maintain a temperature differential of 10 degrees Fahrenheit or more between the lowest air temperature and the temperature of the cooling fluid. This temperature differential is required to achieve significant heat transfer between the heated air and the cooling fluid. In the typical prior

art embodiment discussed above, this would require cooling fluid at an initial temperature of 45 degrees Fahrenheit to cool the entering 75 degrees Fahrenheit air to 55 degrees Fahrenheit. Conversely using a typical embodiment of the present invention, the cooling fluid temperature need only be approximately 65 degrees Fahrenheit. This increased temperature of the cooling fluid is advantageous in that it enables the mechanism for cooling the fluid to operate more efficiently and it also reduces the probability of condensation on any of the cooling fluid lines.

In another preferred embodiment of the present invention, a separate means may be provided to force air through the heat exchanger, which allows the cooling device of the present invention to absorb greater quantities of heat. As the required amount of heat absorption increases, it becomes necessary to increase the thickness of the heat exchanger, increasing the length of the air path through the cooling fins. This increased obstruction to air flow results in a greater air pressure drop across the heat exchanger. As the pressure drop increases, the velocity of the air decreases, ultimately reducing the amount of heat that the air can absorb from the electronic equipment. As a result, it is beneficial to provide a means of increasing airflow through the heat exchanger to supplement the air flow generated by the electronic equipment's integral cooling fans.

Various air flow means that may be added include centrifugal blowers, cross-flow blowers, axial fans, plug fans, and other equivalents that are known in the art. Each fan type has its own performance advantages and disadvantages. For example, construction using axial fans would be expensive to implement. Axial fans also run relatively slowly, thus limiting the airflow increase that can be obtained. Centrifugal blowers are relatively inexpensive to implement and relatively efficient. The airflow path of cross flow blowers minimizes the space required to generate proper airflow across the heat exchanger. Cross flow blowers are also fairly quiet and provide large air volume throughput at relatively low speeds. Plug fans, also known as backward curved motorized impellers, provide very low sound levels, which is important when numerous devices are to be installed in a single room. Plug fans also have very low power consumption levels and are relatively efficient to operate. Whatever the design of the fan, it is preferable to use multiple fans in each cooling device so that failure of any single fan will not compromise system performance.

Fig. 6A illustrates an embodiment of the present invention, implementing an airflow means. A side view of heat exchanger is shown attached to back of enclosure.

An extension or additional chamber attaches to the back and encompasses heat exchanger. Extension has an outlet for air. An air circulator or fan situates within extension and adjacent outlet. Drawn by fan. air flows from within the enclosure and through heat exchanger where cooled. Finally. cooled air exits outlet and returns to the room. It is understood that a number of air circulators. such as those described above. may sufficiently draw air through the heat exchanger. and therefore. selection of the appropriate mechanism lies within the discretion of one having ordinary skill in the art.

Fig. 6B illustrates an embodiment of a heat exchanger with fans according to the present invention. Heat exchanger installs in an attachment enclosure. Necessary piping and valves, further described below, connect to heat exchanger. A panel then attaches to attachment enclosure. Panel has a plurality of openings to receive fans. The fans may be, for example. propeller or plug fans. as these fans present a thin profile for installing on panel. The attachment enclosure, panel. heat exchanger. piping and fans then installs on a rack enclosure (not shown).

Fig. 7 illustrates an embodiment of a modulating valve and piping arrangement according to the present invention. Adapters attach to an external cooling source (not shown). The external cooling source supplies cooling fluid. such as water. glycol or dielectric fluid. to the heat exchanger (not shown). A tee connects adapters to supply line. Supply line has connection end that connects to the heat exchanger as shown in Fig. 6B.

After passing through the heat exchanger and absorbing heat. cooling fluid leaves the heat exchanger through return line. A return opening on return line connects to the heat exchanger and receives the heated cooling fluid. Return line connects to one coupling of a modulating valve or thermostatic valve. Thermostatic valve also has a second pipe. a supply pipe, attached. Supply pipe connects the thermostatic valve to supply line.

Thermostatic valve has a thermostatic operator that changes the valve position according to temperature control. A temperature sensor and other required controls (not shown) operate thermostatic valve. The valve controls the flow of cooling fluid in the heat exchanger and ensures that the air exiting the heat exchanger is at the same temperature as the room temperature of the computer room in which the enclosure is housed. Thermostatic valve attaches to a tee coupling that connects the valve to

adapters. Adapters connect to the external cooling source and returns cooling fluid to the external cooling source.

Another embodiment of the invention is illustrated in Fig. 8. In this embodiment, cooling apparatus is contained within cabinet and mounted on rack. The general principles of operation of this embodiment are substantially the same as the embodiments discussed above, however, the airflow path is different. In the airflow path of the present embodiment, air is drawn in through the front of enclosure. After passing through electronics and absorbing heat therefrom, the air passes through the interior of enclosure and is drawn back through cooling apparatus. Cooling apparatus, which operates in the same manner as described for the previous embodiment absorbs the heat from the air flow and rejects this heat into the cooling fluid delivered to the external source (not shown). Blower draws air through the cooling apparatus, which may be of the designs that are known in the art. The cooled air then returns to electronics again traveling through enclosure.

In this embodiment, the cooling apparatus of the present invention allows the electronics enclosure to present a neutral heat load to the computer room by keeping the heated air contained within the enclosure. The heat produced by electronic equipment within enclosure is ultimately rejected outside the room by the cooling fluid.

Additional modifications and adaptations of the present invention will be obvious to one of ordinary skill in the art, and it is understood that the invention is not to be limited to the particular illustrative embodiments set forth herein. It is intended that the invention embrace all such modified forms as come within the scope of the following claims.

**CLAIMS:**

1. A cooling system for an enclosure containing heat-producing equipment. said cooling system comprising an air-to-liquid heat exchanger; wherein said heat exchanger absorbs heat from air exiting said enclosure and expels the heat outside an environment containing said enclosure.

2. The cooling system of claim 1, wherein said heat exchanger further comprises an air vent, whereby air present in said heat exchanger is expelled when said heat exchanger is charged with liquid.

3. The cooling system of claim 1, further comprising a fan situated to move air through said heat exchanger.

4. The cooling system of claim 3, wherein said fan is selected from the group consisting of a centrifugal blower, a cross-flow blower, an axial fan and a plug fan.

5. The cooling system of claim 3, wherein said heat exchanger and said fan attach to said enclosure.

6. The cooling system of claim 1, further comprising a valve regulating refrigerated liquid flow through said heat exchanger.

7. The cooling system of claim 6, further comprising:

a temperature sensor sensing a temperature of air exiting said heat exchanger: and

a temperature controller coupled to said sensor and modulating said valve to said temperature of said air exiting said enclosure a temperature approximately equal to the air in the environment.

8. An enclosure containing heat-producing equipment, comprising:
an air inlet for admitting air from an environment containing said enclosure said air absorbing heat from said equipment;
an air outlet for expelling heated air from said enclosure; and
an air-to-liquid heat exchanger adjacent to said air outlet, said heat exchanger absorbing heat from said heated air and expelling said heat outside said environment using a refrigerated liquid as a heat transfer medium.

9. The enclosure of claim 8, further comprising a fan disposed to force air through said heat exchanger.

10. The enclosure of claim 9, wherein said fan is selected from the group consisting of a centrifugal blower, a cross-flow blower, an axial fan and a plug fan.

11. The enclosure of claim 10, further comprising a modulating valve for regulating refrigerated liquid flow through said heat exchanger.

12. The enclosure of claim 11, further comprising a temperature sensor sensing temperature of the air exiting said heat exchange and a temperature controller modulating said valve in response to said temperature to ensure that the air exiting said heat exchanger is at a temperature approximately equal to a temperature of said environment.

13. An enclosure containing heat-producing equipment, comprising:
an air inlet for admitting air from an environment containing said enclosure, said air absorbing heat from said equipment,
an air outlet for expelling the air from said enclosure
means for exchanging heat from the air with a refrigerated liquid;
whereby the air returns to said environment at a temperature approximately equal to the temperature of said environment.

14. The enclosure of claim 13, further comprising means for moving the air through said means for exchanging heat.

15. A cooling apparatus for an enclosure containing heat-producing equipment. comprising:

an air-to-liquid heat exchanger installed in said enclosure. said heat exchanger absorbing heat from air passing through said heat exchanger and rejecting the heat outside an environment containing said enclosure; and

a fan disposed to induce airflow through said heat exchanger.

16. A method for cooling an enclosure containing heat-generating equipment, the method comprising:

drawing air into said enclosure from an environment containing said enclosure;

passing the air in the vicinity of said heat-generating equipment to absorb heat from said equipment;

passing the heated air through an air-to-liquid heat exchanger, whereby a refrigerated liquid absorbs heat from the air;

returning the air to said environment; and

rejecting heat from said refrigerated liquid outside said environment containing said enclosure.

17. The method of claim 16, further comprising modulating refrigerated liquid flow through the heat exchanger so as to regulate a temperature of said air returned to said environment at a temperature approximately equal to a temperature of said environment.

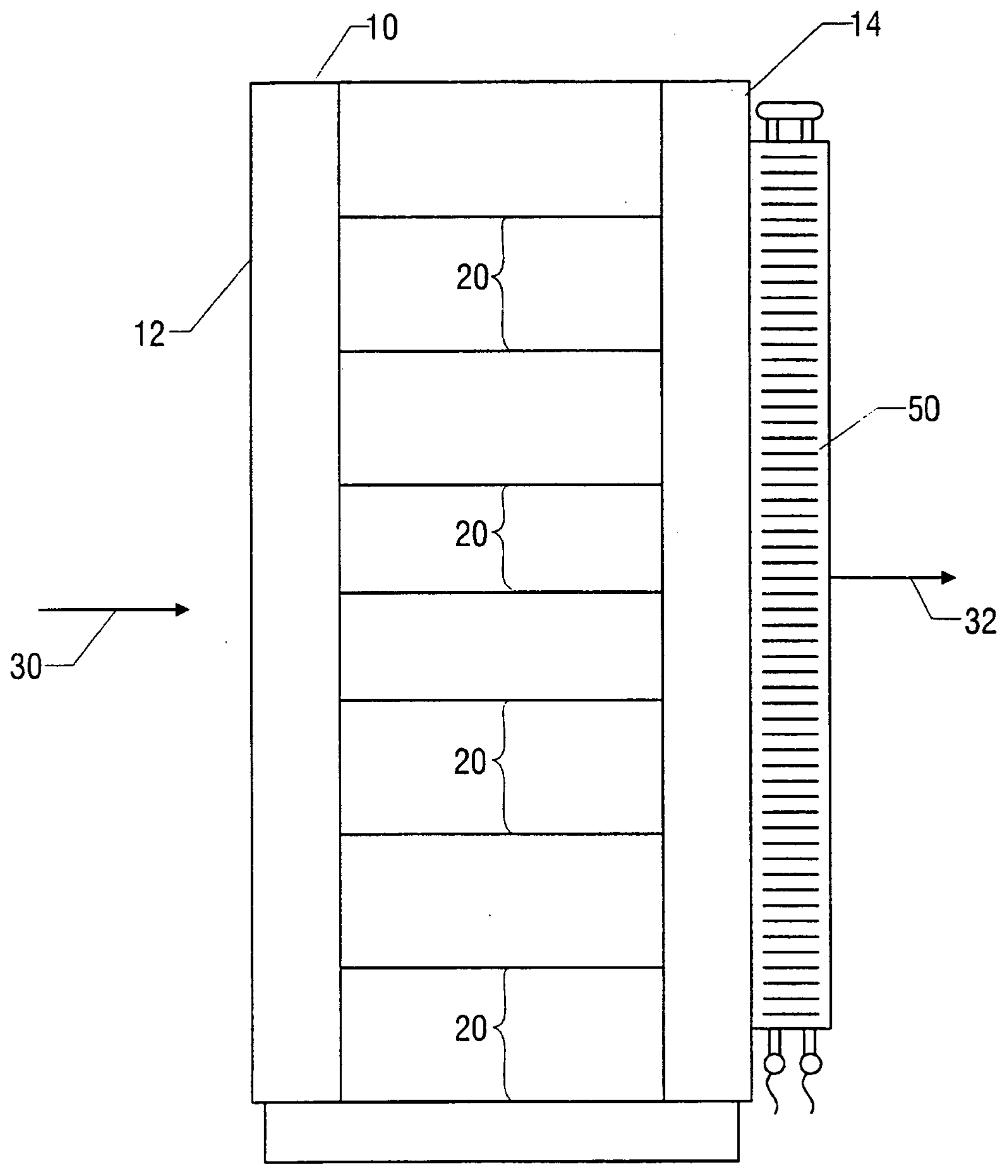


FIG. 1

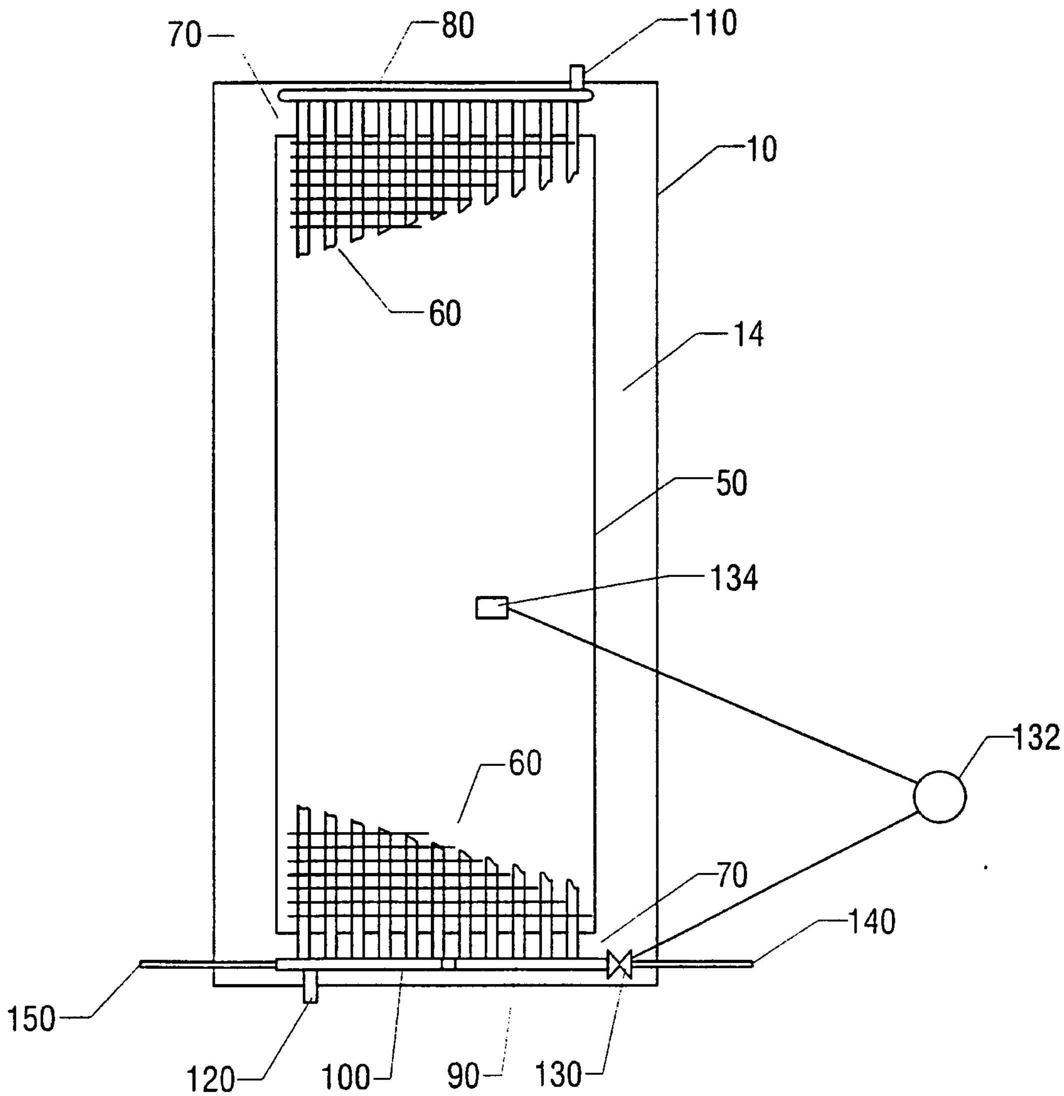


FIG. 2

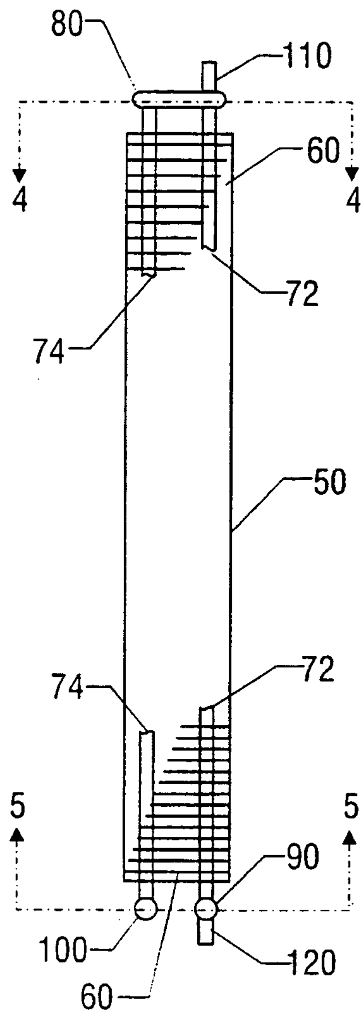


FIG. 3

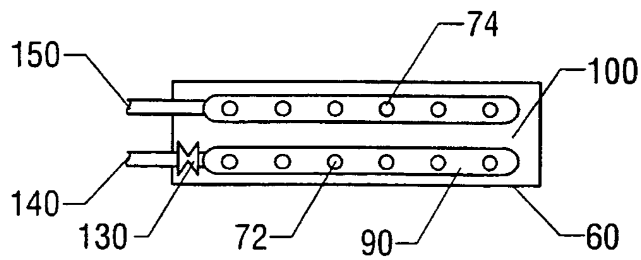


FIG. 4

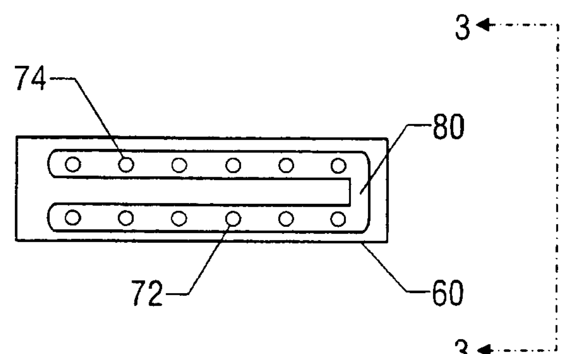


FIG. 5

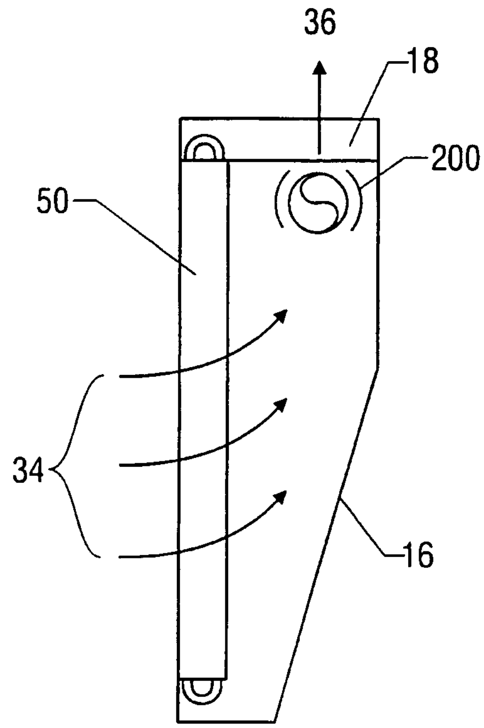


FIG. 6A

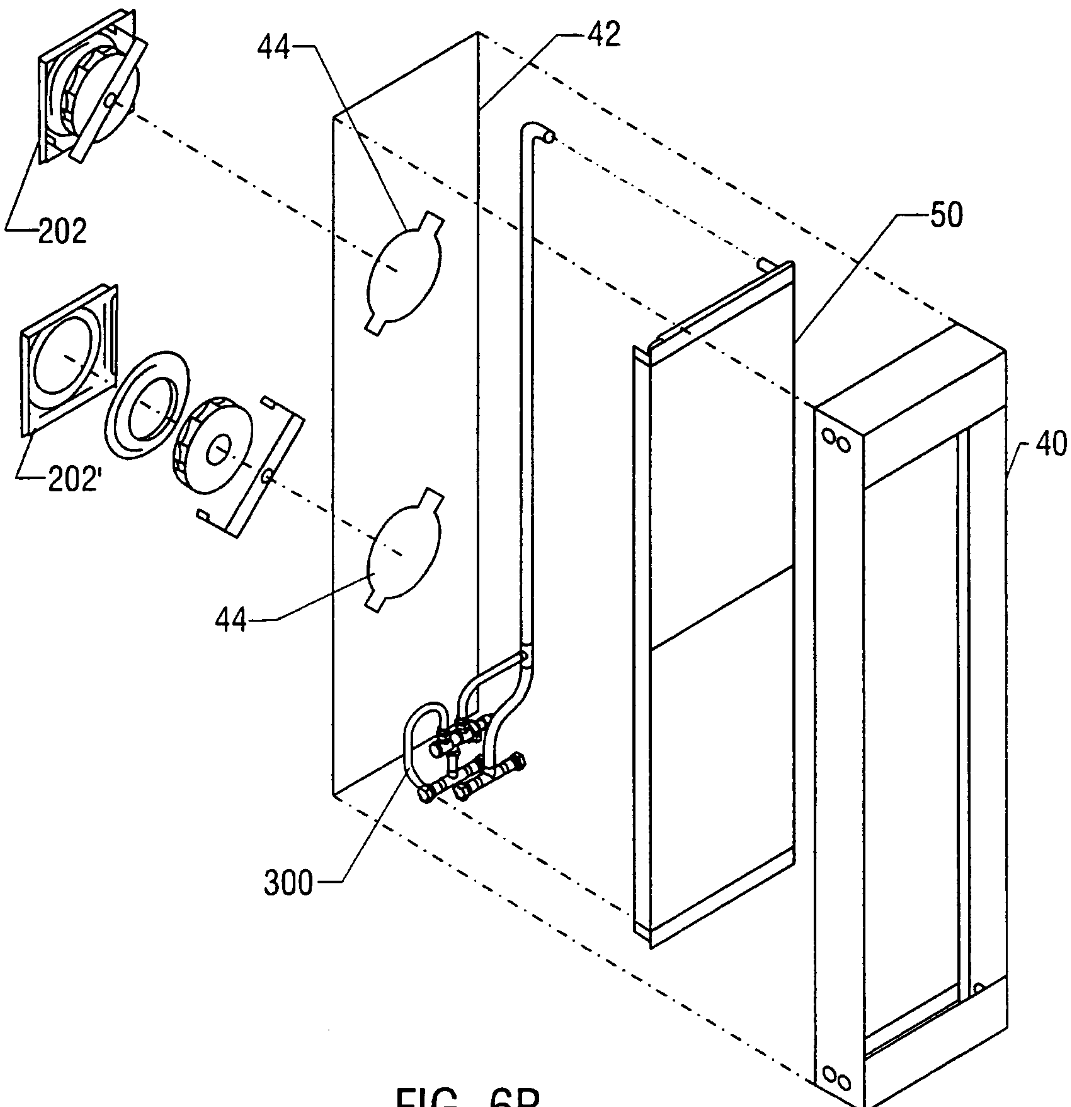


FIG. 6B

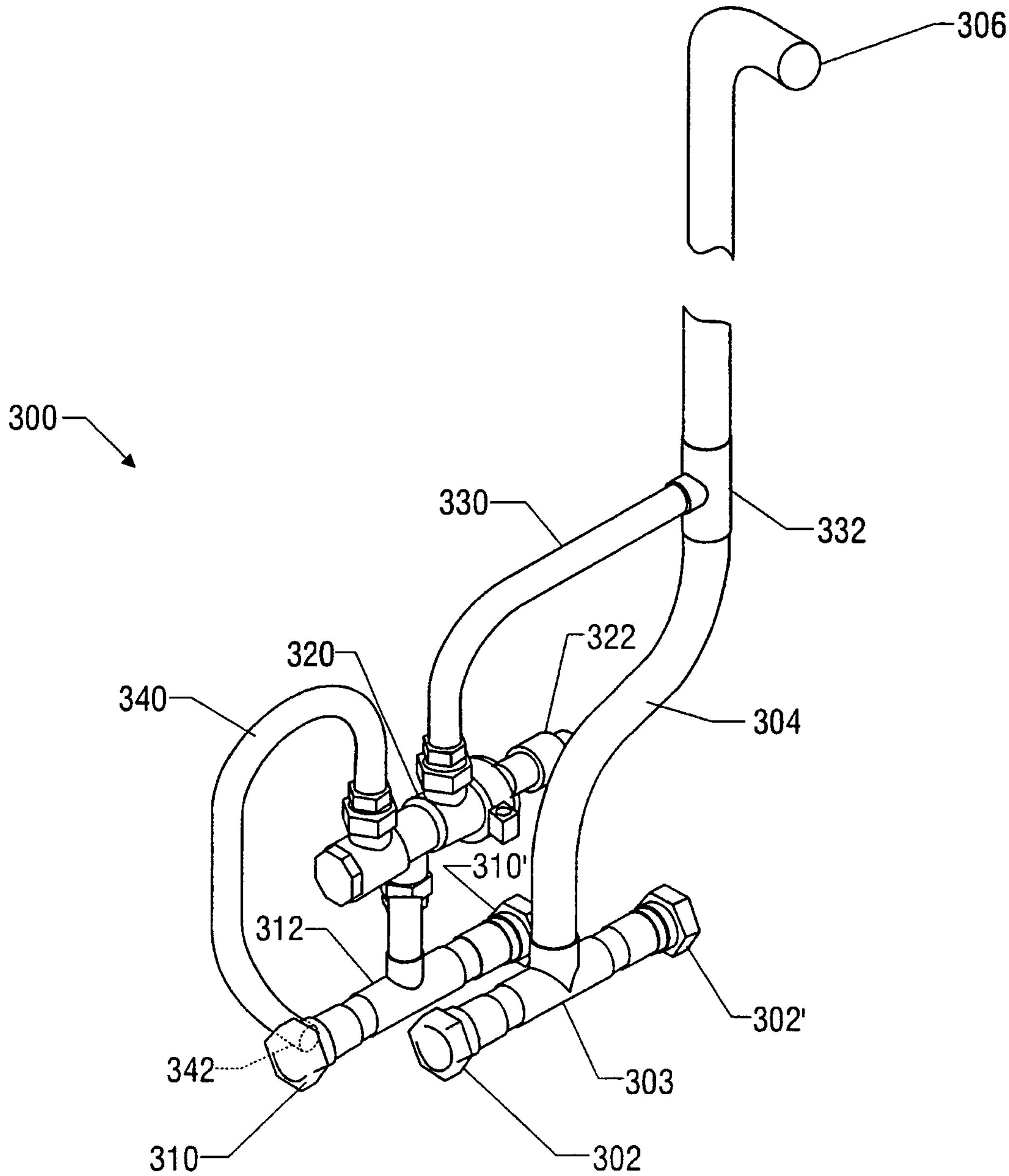


FIG. 7

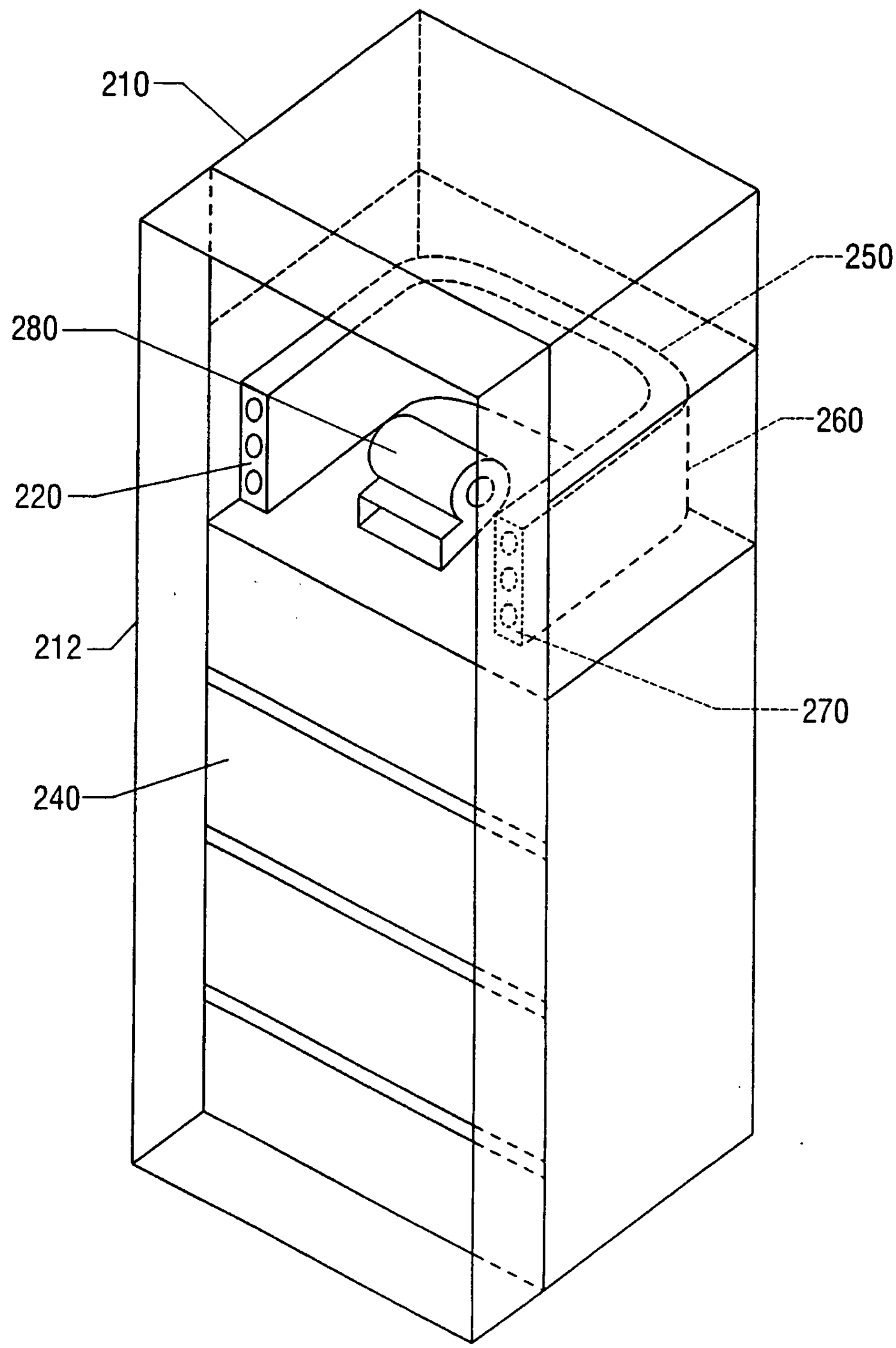


FIG. 8